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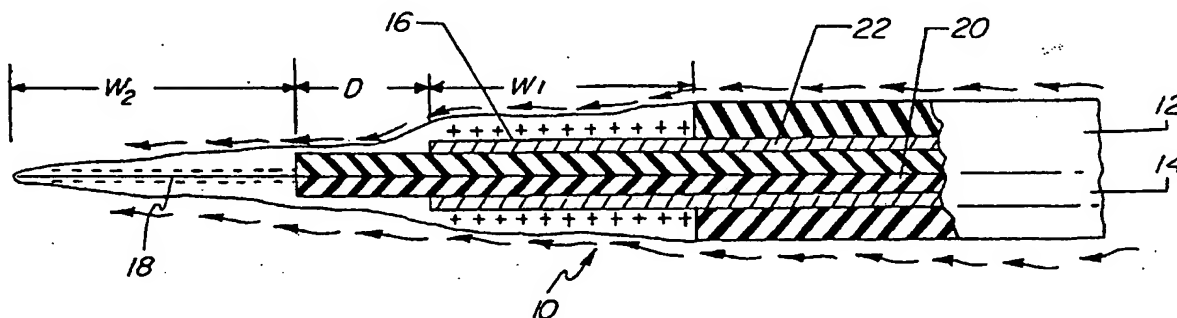
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(54) Title: **APPARATUS AND METHOD FOR MEASURING FLUID FLOW**

(57) Abstract

A method and apparatus for measuring the flow rates of fluids is disclosed. The apparatus comprises a probe (10) which may be placed in a fluid inside a vessel, such as a blood vessel. The probe (10) comprises at least one pair of conductors (16, 18) to which the circuit (15) provides a small current. As ions are disordered or migrate between at least one of the conductors and the fluid, a current or charge is caused to flow between the conductors (16, 18). The circuit (15) measures this current using a differential amplifier (66) and generates an output signal corresponding thereto. The output signal is then displayed on a monitor (80). Because the current flow is closely related to the rate of flow of the fluid past the probe, an accurate measurement of the flow rate is obtained.

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APPARATUS AND METHOD FOR MEASURING FLUID FLOW

Background of the Invention1. Field of the Invention

This invention relates to a method and
5 apparatus for measuring the flow rate of a fluid and,
more particularly, to an apparatus and method for
measuring fluid flow rate in a vessel by monitoring the
movement of ions between at least one of a plurality of
conductors and the fluid.

2. Description of Related Art

10 Diagnostic catheters have heretofore been
provided measuring intravascular pressure and blood flow
using thermal dilution, dye dilution and oxygen
consumption methods. Intravascular catheters have also
15 been developed which measure instantaneous flow velocity
utilizing ultrasonic Doppler transducers to measure the
"Doppler shift" created by movement of red blood cells,
acting as targets, with the blood vessel or organ to
which a measurement is being made. Doppler systems of
20 the past typically used Doppler catheters which were only
useful for the measurement of flow velocity within a
small sample volume contained within the blood vessel of
interest.

Other methods, systems and apparatuses have
25 been designed to measure flow rate using ultrasonic
techniques. For example, U.S. Patent No. 5,174,295
discloses a system for measuring characteristic of flow
of liquid in a vessel of a patient comprising a
transducer positioned in a vessel in a patient of
30 supplying ultrasonic energy. The transducer produced a
substantially uniform beam which encompassed the vessel.
The transducer received ultrasonic energy back scattered
from the plasma and red blood cells and provides an
electrical output signal which was detected by a detector

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which generated a moment signal in response thereto. The signal was then normalized to provide an output characteristic of the flow of the liquid in the vessel.

A disadvantage of the ultrasonic systems of the past was that they required relatively high driving voltages. Another disadvantage is that they were often complex in design and it was sometimes difficult to maintain stability. For example, in ultrasonic systems which use coaxial cable, the coaxial cable is possessed of capacitance. In general the smaller the overall diameter of the cable, the higher its capacitance. Cable capacitance tends to attenuate high frequency AC signals. As cable capacitance increases, the attenuation increases and this attenuation can become significant as cable diameters become smaller and smaller, such as would be required for use with a catheter. This attenuation is undesirable. In addition, these systems typically used a cable having a fairly large capacitance. The impedance and capacitance often adversely affected the signal-to-noise ratios which, in turn, affected the ultimate flow reading.

As mentioned above, thermal dilution devices have also been used to measure fluid flow rates. In general, these devices provided a thermal conductor, such as a thermistor, which was energized with a current to cause the thermal conductor to be set at a desired temperature. As fluid flowed past the thermistor, heat was dissipated by the fluid. Additional current was supplied to the thermistor to maintain the temperature of the thermistor at a predetermined level. The change in additional current was then measured, thereby providing an indication of the flow rate of the fluid. To maintain the current levels needed, the thermal dilution device often required voltage input levels of, for example, 1.5 volts at 30 milliamps for 0.045 watts heating at the thermistor site.

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A problem with the thermal dilution devices of the past is that they tended to be slow in measuring flow rate. In addition, sometimes their accuracy depended in large part on the mass of the thermal conductor.

- 5 Finally, they also typically required relatively high current levels to cause the temperature of the thermal conductors to be maintained at the desired temperature.

Still another problem with flow measuring instruments of the past is that they were not typically
10 multifunctional in that they were not typically designed with other sensing apparatus. For example, they did not include an optical sensor for visual inspection in conjunction with flow measuring. Also, they were not typically used with balloon catheters of the type used
15 in heart catheterization procedures.

What is needed, therefore, is a measuring device, method and system which overcomes the problems of the prior art and which provides an accurate, yet relatively inexpensive way to measure the flow rate of a
20 fluid, like blood, and which can be used in conjunction with other instruments or equipment (such as optical sensors or balloon catheters).

Summary of the Invention

It is, therefore, a primary object of this
25 invention to provide a measuring device for measuring the flow rate of a fluid, such as blood, by measuring the movement of ions between at least one conductive surface and the fluid using a micro current or small amount of current flow.

30 In one aspect, this invention comprises a method for measuring the flow rate of a moving fluid, said method comprising the step of: generating a signal corresponding to the transfer of charge between a pair of conductors positioned in said fluid.

35 In another aspect, this invention comprises a method for measuring the amount of blood flow in a vessel

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having an occlusion; the method comprises the steps of:
placing a probe having at least one conductive set near
the occlusion; and generating a signal corresponding to
the displacement of ions from at least one of the
5 conductors as the blood flows past the conductor.

In still another aspect, this invention
comprises a flow meter for measuring flow in a vessel
comprising: a probe having a plurality of conductors; a
circuit coupled to said plurality of conductors for
10 generating a signal corresponding to the displacement of
ions on at least one of said plurality of conductors as
fluid flows past said probe; and a display coupled to
said circuit for receiving said signal and generating a
display corresponding thereto.

15 Another object of this invention is to provide
a method and apparatus which can measure flow in a vessel
using a controlled or servo controlled current source of
10 microamperes or less.

Another object of this invention is to provide
20 a method and apparatus which is easy to use and which is
not restricted to measuring the flow rate of blood.

Still another object of this invention is to
provide a method and apparatus which inexpensive to
manufacture.

25 An advantage of this invention is that it
provides a method and apparatus that can measure fluid
flow in a vessel using a relatively small amount of
current.

Another advantage of this invention is that it
30 provides an apparatus and method which is relatively
simple in design relative to the flow measuring devices
of the past.

Still another advantage is that it is
relatively easy to use and inexpensive to manufacture
35 when compared to flow measuring devices of the past, such
as the Doppler devices mentioned above. Further, it

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facilitates the use of cables having relatively high capacitance.

Yet another advantage of the invention is that it may be used with other types of instruments, or
5 equipment, such as balloon catheters or optical sensors.

These objects, advantages and features of the invention will become apparent from a reading of the following description, drawing and claims.

Brief Description of the Drawing

10 Fig. 1 is a view of a flow meter according to one embodiment of the invention;

Fig. 2 is a fragmentary view of a probe, showing the electrical charge associated with a pair of conductors;

15 Fig. 3 are illustrative voltage waveforms showing voltage being proportional to a current flowing through a vessel;

Fig. 4 is a schematic of a circuit used in one embodiment of the invention;

20 Fig. 5 is a sectional view showing a probe positioned relative to an occlusion in a vessel of a patient;

Fig. 6 is a fragmentary view showing the flow meter having an optical sensor;

25 Fig. 7 is a sectional view taken along the line 7--7 in Fig. 6, showing the flow meter used with a balloon catheter; and

Fig. 8 is another view of a probe having two conductors and of a common ground; and

30 Fig. 9 is a schematic view of the probe shown in Fig. 8.

Description of the Preferred Embodiment

Referring now to Fig. 1, a flow meter 8 according to one embodiment of the invention is shown.

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The flow meter 8 comprises a probe 10 which senses or measures the actual flow rate of a fluid.

As best shown in Fig. 1, flow meter 8 comprises a computer 8a having software (not shown) which is capable of processing information inputted to the computer 8a. In this regard, information may be input into a computer 8a in a number of conventional manners, including through a keyboard 8b, through disc drives 8c, or through an interactive screen, touch screen, stylus, digitizer or other input device, including display 8d. The computer 8a in the flow meter 8 can output information in any conventional manner, such as through a printer 8e, disc drives 8c, display 8d, or video monitor 8i.

It is to be noted that the software in computer 8a, which enables flow meter 8 to process data and generate a plurality of output images, such as images 8f, 8g, and 8h. For example, computer 8a can process data such that a display 8d shows a graphical representation of an EKG (8f), a graphical presentation of a flow rate (8g), proximal and distal of an occlusion in the vessel 11, and a graphical representation (8h) of pressure in vessel 11 over time (such as before, during and after angioplasty procedures). Thus, it should be apparent that flow meter 8 comprises software and hardware which is capable of producing a variety of flexible displays in a format which is easily selected by a user and which promotes greater utility and ease of use, thereby facilitating the ease of use of the flow meter 8.

In addition, the video monitor 8c displays a video image in response to an optical signal generated by an optical sensor which is described in more detail below in relation to Figs. 6 and 7.

The probe 10 may be configured as generally illustrated in Fig. 2. As shown, probe 10 may be of a size appropriate for insertion into a vessel, such as a blood vessel 11 (Fig. 5). The probe 10 is of a size and

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configuration to permit movement through a vessel 11, for example, to a point of suspected occlusion 13 (Fig. 5). Probe 10 (Fig. 2) may comprise a dielectric sheath 12 fitted with a dielectric rod 14. A conductor or

5 conductive wire 18 extends longitudinally through rod 14 and extends outwardly therefrom for surface contact with a fluid (for example, blood) flowing past the probe 10. A portion of the exposed surface of rod 14 is coated with another conductor or layer 16 of conductive material.

10 Thus, layer 16 and wire 18 comprise a conductor set. As explained later herein, this conductive set may comprise more conductors if desired. Lead lines 20 and 22 are connected to wire 18 and layer 16, respectively, and ultimately to a circuit 15 (Fig. 4).

15 It is to be noted that the probe 10 may be provided with a protective coating 17 which protects wire 18 and layer 16, while permitting the migration or transfer of ions between one or both wire 18 and layer 16 and the fluid. The protective coating 17a may also be

20 useful to provide an outer configuration which is easy to insert in vessel 11 and which will minimize or reduce damage to the vessel as it is being inserted therein. The protective coating 17 may be Teflon, amorphous glass, plastic or any suitable coating which does not prevent

25 ionic migration between wire 18 and layer 16.

In the embodiment being described, layer 16 and wire 18 have a width $W1$ and $W2$, respectively, which are each on the order of about 4-8 mm wide (as viewed in Fig. 2). The layer 16 and wire 18 may be any size which is

30 capable of carrying a small current of 10 microamperes of current or less. It should also be noted that the distance D (Fig. 2) between the wire 18 and layer 16 is approximately 4-8 mm in the embodiment being described.

In operation, lines 20, 22 are connected across

35 a small potential difference. This enables a small current in the order of about 10 microamperes or less to flow between wire 18 and layer 16. As best illustrated

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in Fig. 1, this causes surface charges of opposite polarity to build up on wire 18 and layer 16 which, in turn, establishes an ionic balance or stability which tends to oppose the current flow. However, the flowing or stirring action of the fluid as it flows past probe 10 tends to disturb the local ordering of ions at and near wire 18 and layer 16. The disturbance causes surface charge and ordered ions to be "displaced" or transferred between at least one of either the wire 18 or layer 16, thereby permitting the current to continue flowing between wire 18 and layer 16. Thus, as disordered ions migrate or are conveyed towards the sensing elements 16 and 18 by virtue of fluid motion, the ordered ions are displaced or transferred between at least one of the wire 18 or layer 16 and the fluid, a resultant current or charge is caused to flow between the wire 18 and layer 16. It has been found that the level of such current flow is closely related to the rate of flow of fluid past the probe 10. Accordingly, an accurate measure of the flow rate is provided. Thus, current flow is directly related to the degree of local ionic order or disorder at or near the wire 18 or layer 16.

It will be appreciated that the illustrated apparatus and method is very useful for monitoring all types of fluid flow, such as fluid flowing in a vessel. In particular, it is very useful for monitoring, for example, blood flow in a blood vessel 11 (Fig. 5) upstream and downstream from a region of occlusion. While the volume flow rate of blood upstream and downstream from the occlusion 13 must be the same when averaged over a pumping cycle, the pressure variations upstream of the occlusion 13 cause a circulating localized blood flow which is sensed by the probe 10. Depending upon the amount of blockage caused by the occlusion 13, the downstream flow rate may be substantially reduced in comparison to the upstream flow rate.

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Fig. 3 illustrates the current which may be expected from the probe 10 when there is little or no blockage (waveform 30) and when there is blockage (waveform 32) caused, for example, by an occlusion 13..

5 Waveform 30 is characterized by a relatively large current flow which is well modulated by coronary pumping. In contrast, waveform 32 depicts a substantially reduced rate of change in velocity and pressure which, in turn, provides an indication of the blood flow rate. The probe
10 10 measures a current having substantially less magnitude and modulation.

A current sensing circuit or electrical circuit
15 for supplying current to probe 10 and recording the responsive reaction to a flowing fluid stream is
15 illustrated in Fig. 4. Specific identifications for the illustrated components are set forth in Table I.

TABLE I

| | <u>REFERENCE NUMERAL</u> | <u>IDENTIFICATION</u> |
|----|--------------------------|-------------------------|
| | 40 | 25K |
| 20 | 42 | 25K |
| | 44 | 7.8K |
| | 46 | 2N4117T |
| | 48 | 5K |
| | 50 | 2N2222A |
| 25 | 52 | 30K |
| | 54 | 0.1 micro farad |
| | 56 | 10K |
| | 58 | 1/2 LT 1078 |
| | 60 | 0.1 micro farad |
| 30 | 62 | 51 K cermet, 3-1/2 turn |
| | 64 | 51K |
| | 66 | 1/2 LT 1078 |
| | 68 | 51K |

In the example illustrated in Fig. 4, probe 10
35 is inserted into one arm of a bridge arrangement; the

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other arms comprising resistors 40, 42 and 44. Resistors 40 and 42 have an equal value, so that the potential difference across nodes 41, 43 is proportional to the difference in the current flowing through those
5 resistors. Resistor 44 has a resistance which will cause a nearly equal, but different, current flow through resistors 40, 42 and thus maintain a small potential across nodes 41, 43.

The output potential across nodes 41, 43 is
10 applied to the input side of differential amplifier 66. Differential amplifier 66 has a conventional feedback path through resistor 68 and back to an active terminal 66a. A small current flows through this path and into node 43. Thus, a current flows through probe 10 which is
15 the sum of the currents through resistors 40 and 68.

The current for resistor 44 and probe 10 is supplied by a current source 70 coupled to the bridge at node 47. In the embodiment being described, the current source 70 comprises transistor 50, resistor 52, capacitor
20 54 and potentiometer 56. In the embodiment being described, the current source 70 provides a current of approximately 10 microamperes or less. This relatively small driving current is advantageous because it does not expose, for example, either a user of the probe 10 or a
25 patient to an undesirable level of current. Also, sensors 19 and 20 may be used in a side-by-side manner for providing multiple sensing signals, colorimetry, spectrophotometry, fluorescence, analytical qualitative and quantitative analysis.

30 A current sink or drain 75 is coupled to the bridge at node 49. The current drain 75 comprises a field effect transistor 46 and resistor 48.

A reference potential for differential
amplifier 66 is provided by a variable potential source
35 78 comprising potentiometer 62, capacitor 60, differential amplifier 58 and resistor 64. Potentiometer 62 is adjusted to supply a reference potential. The

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reference potential may be charged, thereby permitting the operator to establish a desired reference level for the final output from differential amplifier 66, such as zero. For example, the operator may adjust potentiometer 5 62 to compensate for system offset and establish a reference level of zero. The output signal from differential amplifier 66 is supplied on line 79 to a suitable monitor or display 8d (Fig. 1) such that graphical representation 8g may be produced.

10 The potential applied on line 79 to monitor 80 is proportional to the current flow through probe 10, as described above and as illustrated by waveforms 30 and 32 of Fig. 3. Thus, monitor 80 will display a trace
15 corresponding to variations in the speed or flow rate of the fluid flowing past probe 10.

 It will be appreciated that the current applied to probe 10 may be servo-controlled, modulated, encoded or otherwise modified. Furthermore, the technique of this invention may be used to measure the flow of a wide
20 range of conductive, ionic, electrolytic or dielectric solutions. For use in applications wherein fluid flow speed must be accurately measured or carefully controlled, the circuit of Fig. 4 may be easily calibrated. Calibration simply involves placing probe 10
25 in a reference solution flowing at a reference speed and then recording the output from differential amplifier 66. Output values may be recorded for a series of reference solutions and over a range of different speeds for storage in tabular form, for example, in the computer 67
30 (Fig. 1). Subsequently, actual measurements may be taken and compared to the predetermined rate and the difference therebetween displayed on monitor 80.

 A method for measuring flow rate of a fluid in a vessel will now be described. For purposes of
35 illustration only, the method will be described as it may be used for measuring flow rate of blood in a vessel 11 (Fig. 5) around occlusion 13. As best shown in Fig. 5,

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probe 10 is inserted into vessel 11 in blood at or near the point of occlusion 13 so that the wire 18 and layer 16 are positioned near occlusion 13. For this purpose, it may be desired to place the probe 10 on the end of a catheter (not shown). The circuit 15 is then energized with a small current on the order of about 10 microamperes or less by current source 70. In the manner described earlier herein, circuit 15 measures the transfer or displacement of ordered layers of ions between one or more of the conductive surfaces (wire 18 and layer 16) and the blood. The circuit 15 generates a signal on line 79 corresponding to the measurement obtained. The signal is then displayed on monitor 80 (Figs. 1 and 4) to give the user a waveform corresponding to the flow rate of the blood near the occlusion 13.

In the example being described, the probe 10 may first be positioned upstream of the occlusion 13, as shown in Fig. 5. Because of the relatively small size of the probe 10 relative to the vessel 11 and depending on the size of the occlusion 13, the probe 10 may then be moved until the wire 18 and layer 16 are positioned downstream of the occlusion 13. Another measurement representing the fluid flow rate downstream of the occlusion 13 may then be taken. The upstream and downstream flow measurements can subsequently be compared to provide accurate information about the flow rate past the occlusion 13, the size of the occlusion 13, and the amount of blockage caused by the occlusion 13. Once all desired measurements have been taken, the probe 10 may be removed from the vessel 11.

Referring to Figs. 8 and 9, it should be understood that probe 10 could be configured such that two identical circuits (not shown) can be used with a single probe 10 having a plurality of conductors for generating multiple signals. The set of conductors 16 and 18 comprises a common ground and two conductors which may be individually coupled to their own sensing circuit

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15 or to conventional switching circuitry (not shown) which would permit a single circuit 15 to be used with the conductors 16 and 18. For example, referring to Fig. 4, mode 43 or mode 47, but not both, could be common to the "shared" electrode. The outputs from the identical circuits would either be isolated or pass through a sufficiently high value current limiting resistance which may be applied to a suitable high impedance input device so as to render current leakage between the two circuits negligible. It should be appreciated that this isolation may not be required in all applications. Using a probe 10 which is capable of generating separate measurement signals representing fluid flow rate permits an upstream and downstream measurement to be taken without having to re-position the probe 10. When configured with two pairs of conductors 16 and 18 which are separated by a distance X (Fig. 8) as shown, the upstream and downstream flow measurements mentioned above to be taken without moving the probe 10. Another embodiment is shown in Fig. 6 wherein the flow measuring system and method further comprises an optical sensor 19. The probe 9 illustrated in Fig. 6 comprises a first optical sensor 19, around which the conductor or wire 18 is placed. A second optical sensor 21 is then positioned around wire 18 and surrounded by the conductor or layer 16. Finally, an insulator, such as protective coating 17, is then molded over layer 16.

The probe 9 permits flow measuring as described herein, regarding probe 10, but probe 9 also permits optical sensing which may be useful for visually inspecting, for example, an occlusion or a wall of an artery if the probe 9 is used in a medical application. The sensors 19 and 21 could comprise a plurality of optical fibers as shown. Note that sensor 21 could be used for illumination while sensor 19 is used for visual inspection or imaging.

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The probe 9 shown in Fig. 6 may be coupled to flow meter 8 such that computer 8a can control the operation of the probe 9 and the information transmitted thereto or received therefrom.

5 Although the example above has been described in connection with measuring blood flow in a blood vessel, it should be appreciated that the method and apparatus of this invention has been found to be effective when measuring flow rates of other types of
10 fluids. For example, it may be used to measure the flow rate of viscous fluids, such as syrup in a beverage dispensing machine.

In addition, it should be appreciated that this method and apparatus could also be used in conjunction
15 with other medical instruments. For example, it could be integrally formed with a balloon catheter, thereby providing means for generating flow measuring and optical feedback information during an angioplasti procedure.

While the method herein described, and the form
20 of apparatus for carrying this method into effect, constitute a preferred embodiment of this invention, it is to be understood that the invention is not limited to this precise method and form of apparatus, and that changes may be made in either without departing from the
25 scope of the invention, which is defined in the appended claims.

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CLAIMS

1. A method for measuring the flow rate of a moving fluid, said method comprising the step of:
generating a signal corresponding to a local disorder of ions associated with a pair of conductors
5 positioned in said fluid as the fluid flows past the conductors.
2. The method as recited in claim 1 wherein said method further comprises the step of:
displaying said signal on a display monitor.
3. The method as recited in claim 1 wherein said generating step further comprises the step of:
coupling said conductors to a current sensing circuit.
4. The method as recited in claim 1 wherein said generating step further comprises the step of:
using a bridge and amplifier in the current sensing circuit.
5. A method for measuring a flow rate of a fluid in a vessel, said method comprising the steps of:
inserting a probe into the vessel and in the fluid, said probe having a pair of electrically
5 conductive surfaces between which a current may flow;
measuring the displacement of ordered ions associated with at least one of said conductive surfaces as fluid flows therepast; and
generating a display which corresponds to the
10 measurement obtained in said measuring step.
6. The method as recited in claim 5 wherein said measuring step comprises the step of coupling a current source to one of said surfaces and a current drain to the other of said surfaces.

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7. The method as recited in claim 5 wherein said measuring step comprises the step of:
coupling an active terminal of a differential amplifier to one of said electrically conductive
5 surfaces.
8. The method as recited in claim 7 wherein said measuring step further comprises the step of:
coupling a current source to the other of said electrically conductive surfaces.
9. The method as recited in claim 8 wherein said current source provides a current of approximately 10 microamperes.
10. A method for measuring flow rate of a fluid in a vessel comprising the steps of:
placing at least two conductive surfaces in
said vessel and in said fluid;
5 causing a current to flow between said at least two conductive surfaces; and
measuring the migration of ions carried by said fluid as said fluid flows past said at least two conductive surfaces.
11. The method as recited in claim 10 wherein said method further comprises the step of:
generating a signal corresponding to said measurement measured in said measuring step.
12. The method as recited in claim 10 wherein said method further comprises the step of:
displaying the measurement obtained in said measuring step.

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13. The method as recited in claim 11 wherein said method further comprises the step of:

displaying said signal on a display monitor.

14. The method as recited in claim 10 wherein said method further comprises the steps of:

optically sensing said vessel and generating a video signal corresponding thereto; and

5 displaying said video signal on a video monitor.

15. A method for measuring the amount of blood flow in a vessel having an occlusion: said method comprising the steps of:

placing a probe having at least one conductor set near the occlusion; and

5 generating a signal corresponding to the disordering of ions from at least one conductor in said conductor set as the blood flows past the conductor.

16. The method as recited in claim 15 wherein said method further comprises the step of:

displaying said signal on a display monitor.

17. The method as recited in claim 15 wherein said at least one conductor set comprises at least two conductors, said generating step further comprises the step of:

5 coupling said conductors to a bridge circuit.

18. The method as recited in claim 16 wherein said generating step further comprises the step of:

coupling an amplifier across said bridge circuit to generate said signal.

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19. The method as recited in claim 15 wherein said probe comprises two pairs of conductors, said method further comprising the steps of:

5 positioning said probe in said vessel such that said occlusion lies substantially between said pairs of conductors, and

generating a first signal corresponding to the blood flow rate proximal of the occlusion and a second signal corresponding to the blood flow rate distal of the
10 occlusion.

20. The method as recited in claim 15 wherein said method further comprises the steps of:

optically sensing said blood and said vessel and generating a signal corresponding thereto; and displaying said signal on a video monitor.

21. The method as recited in claim 15 wherein said method further comprises the steps of:

generating a first signal associated with the blood flowing on one side of said occlusion;
5 generating a second signal associated with blood flowing on another side of said occlusion;
comparing said first and second signals;
displaying the relative difference between said first and second signals on a display monitor.

22. The method as recited in claim 21 wherein said dislodging step further comprises the step of:

recording the relative difference between said first and second signals.

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23. The method as recited in claim 15 wherein said at least one conductor comprises a first pair of conductors and a second pair of conductors, wherein said method further comprises the steps of:

5 generating a first signal with said first pair of conductors, said first signal corresponding to the blood proximal upstream of said occlusion;

generating a second signal with said second pair of conductors, said second signal corresponding to
10 the blood flowing distal of said occlusion;

comparing said first and second signals; and
displaying the difference between said first and second signals on a display monitor.

24. A flow meter for measuring flow in a vessel comprising:

a probe having a plurality of conductors;
a sensing circuit coupled to said plurality of
5 conductors for generating a signal corresponding to the movement of ions on at least one of said plurality of conductors as fluid flows past said probe; and

a display coupled to said circuit for receiving said signal and generating a display corresponding
10 thereto.

25. The flow meter as recited in claim 24 wherein said sensing circuit comprises a bridge, a current source, a current sink and an amplifier which are operatively coupled together and to said plurality of
5 conductors to enable said circuit to generate said signal.

26. The flow meter as recited in claim 24 wherein said probe comprises two conductors which have a spacing therebetween of not more than 10 mm.

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27. The flow meter as recited in claim 24 wherein each of said plurality of conductors have a protective coating.

28. The flow meter as recited in claim 27 wherein said protective coating is Teflon.

29. The flow meter as recited in claim 25 wherein said current source provides a current of 10 microamperes or less.

30. The flow meter as recited in claim 24 wherein said one of said conductors comprises an outer diameter of not more than 0.015 mm or less.

31. The flow meter as recited in claim 24 wherein said probe also comprises an optical sensor for generating an optical signal.

32. The flow meter as recited in claim 24 wherein said vessel comprises an occlusion, said plurality of conductors comprises at least two conductor sets each comprising at least one conductor;

5 said at least two conductor sets enabling said flow meter to measure a first flow rate proximal of said occlusion and a second flow rate distal of said occlusion.

33. The flow meter as recited in claim 32 wherein said at least two conductor sets uses a common ground.

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34. A measuring device for measuring blockage caused by an occlusion in a blood vessel comprising:
a probe for placing in the vessel near the occlusion, said probe having at least two conductors;
5 a circuit coupled to said at least two conductors for generating a signal corresponding to the movement of ions as blood flows past said probe; and
a display coupled to said circuit for receiving said signal and generating a display corresponding
10 thereto.

35. The measuring device as recited in claim 34 wherein said circuit comprises a bridge, a current source, a current drain and an operational amplifier which are operatively coupled together and to said at least two conductors to enable said circuit to generate said signal.

36. The measuring device as recited in claim 34 wherein said probe comprises a pair of conductors which have a spacing therebetween of not more than 10 mm.

37. The measuring device as recited in claim 34 wherein said at least two conductors each have a protective coating.

38. The measuring device as recited in claim 37 wherein said protective coating is Teflon.

39. The measuring device as recited in claim 35 wherein said current source provides a current of 10 microamperes or less.

40. The measuring device as recited in claim 34 wherein one of said at least two conductors comprises an outer diameter of not more than 0.15 mm or less.

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41. The measuring device as recited in claim 34 wherein said probe has two pairs of conductors.

42. A method of measuring the rate of flow of a moving fluid comprising the step of;

inserting a pair of separated and electrically conductive surfaces into said fluid;

5 connecting a current source to one of said conductive surfaces and a current drain to the other of said surfaces;

determining an actual current flow rate between said surfaces by measuring the disorder of ions as said
10 fluid flows past at least one of said conductive surfaces;

comparing said actual current flow rate against a predetermined current flow rate; and

generating a signal corresponding to the
15 difference between said predetermined current flow rate and said actual current flow rate.

43. The method as recited in claim 42 wherein said method further comprises the step of:

displaying said signal on a monitor.

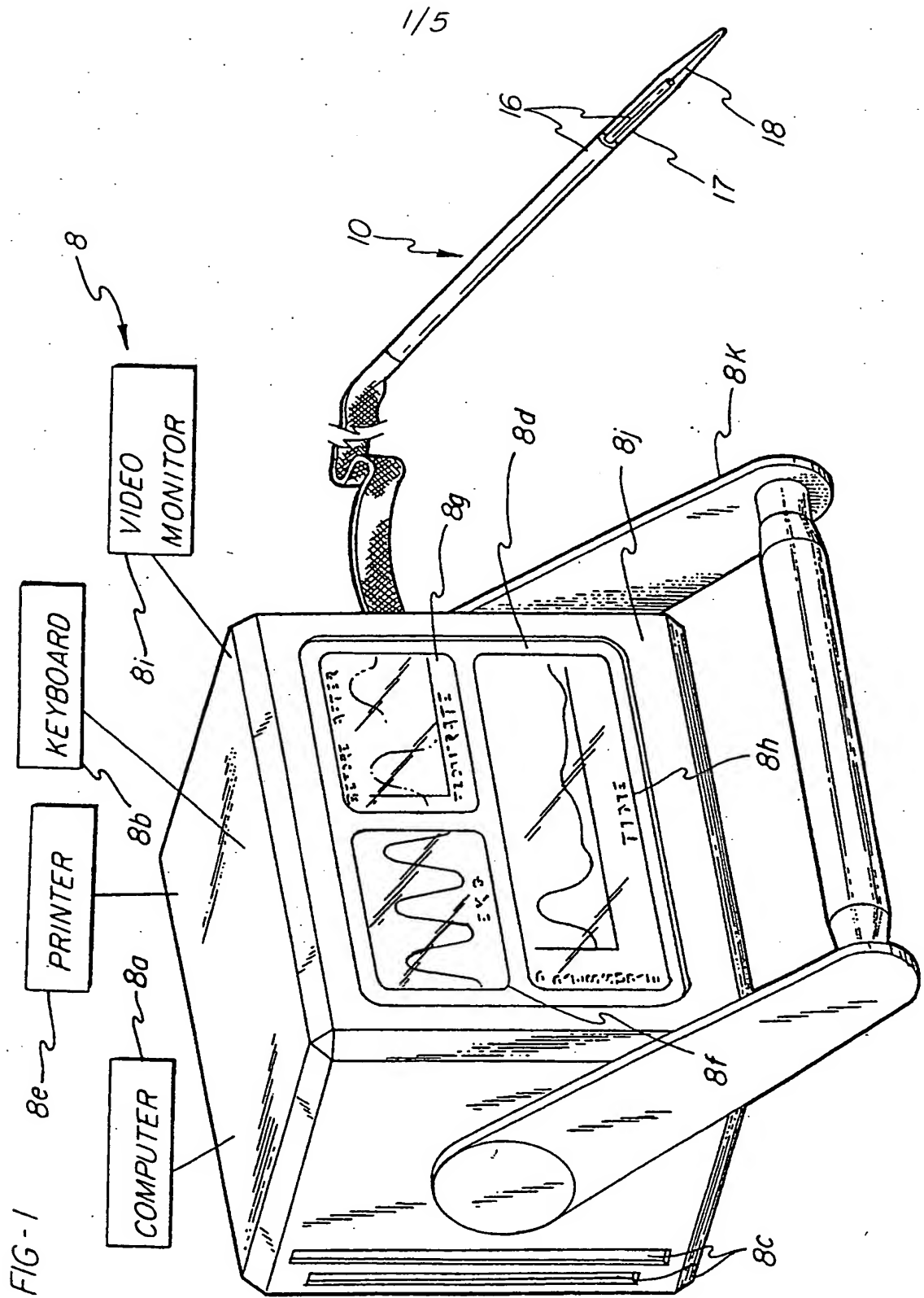
44. The method as recited in claim 42 wherein said current source provides a current of not more than 10 microamperes.

45. The method as recited in claim 42 wherein said generating step further comprises the step of:

using an amplifier coupled to a bridge circuit which, in turn, is coupled to said conductive surfaces to
5 generate said signal.

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46. The method as recited in claim 42 wherein said fluid is blood in a vessel, said method further comprising the steps of optically sensing said vessel; generating an image; and displaying said image.
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FIG-2

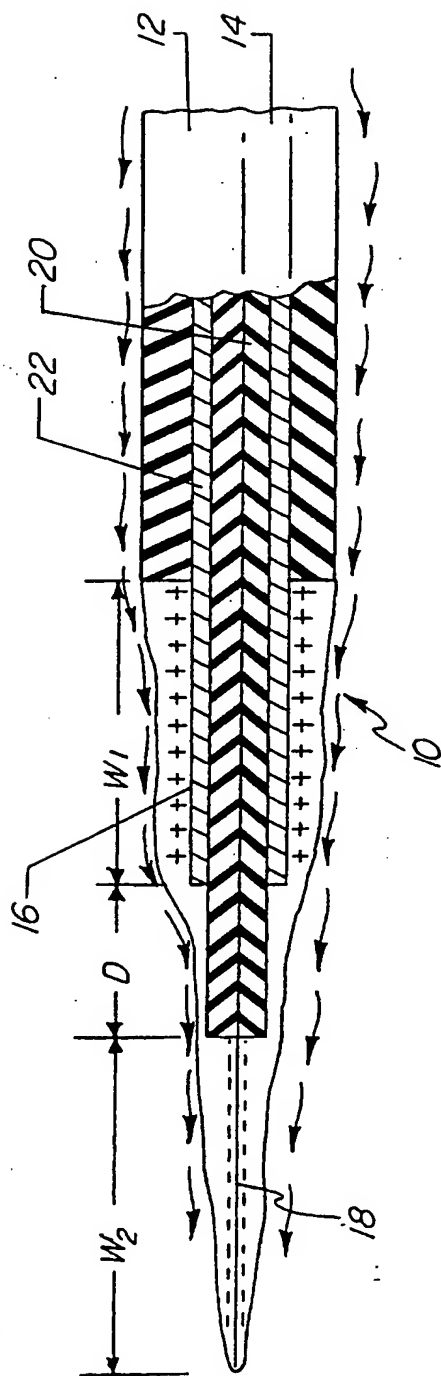
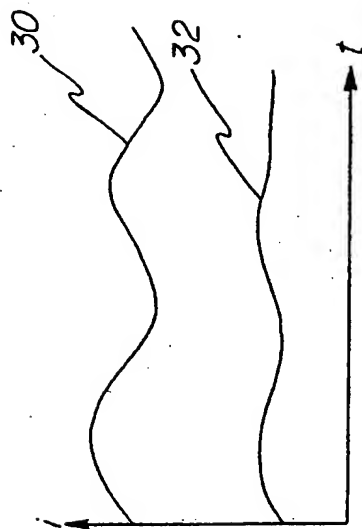
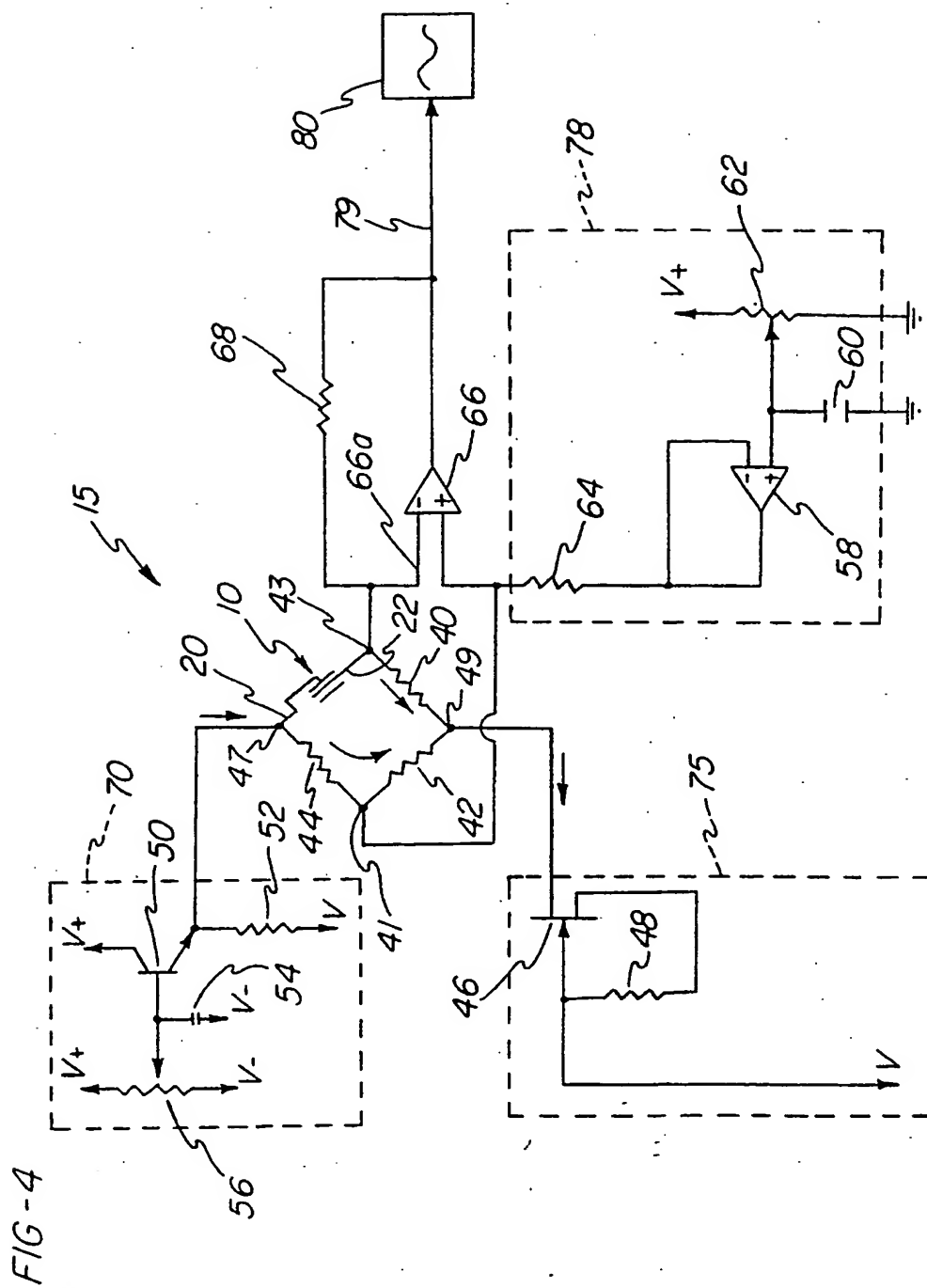


FIG-3



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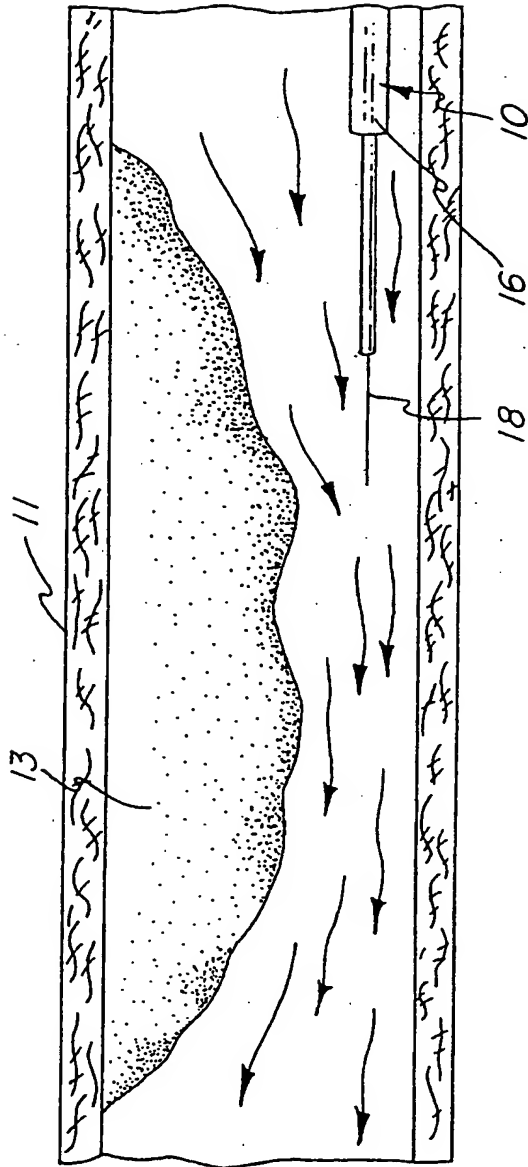


FIG. 5

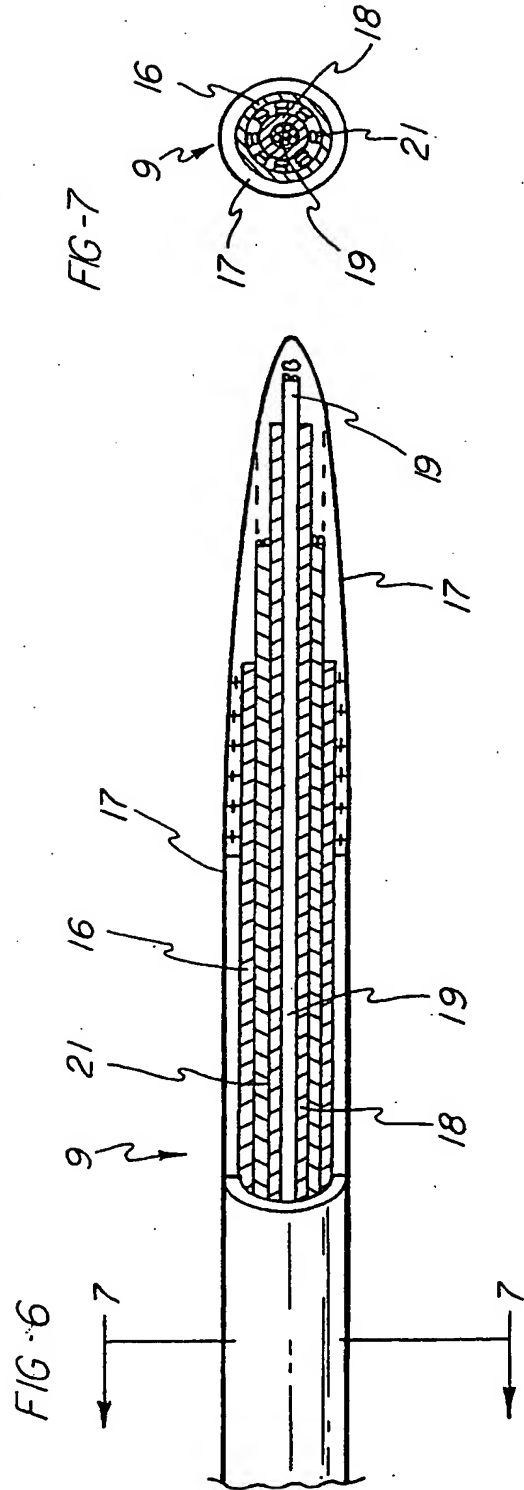
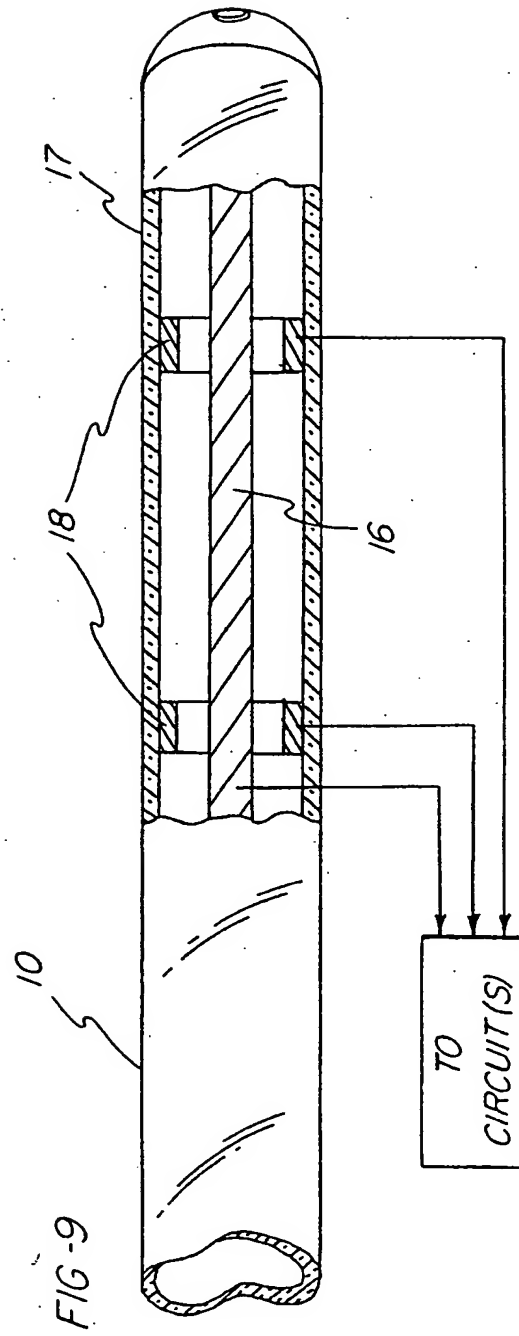
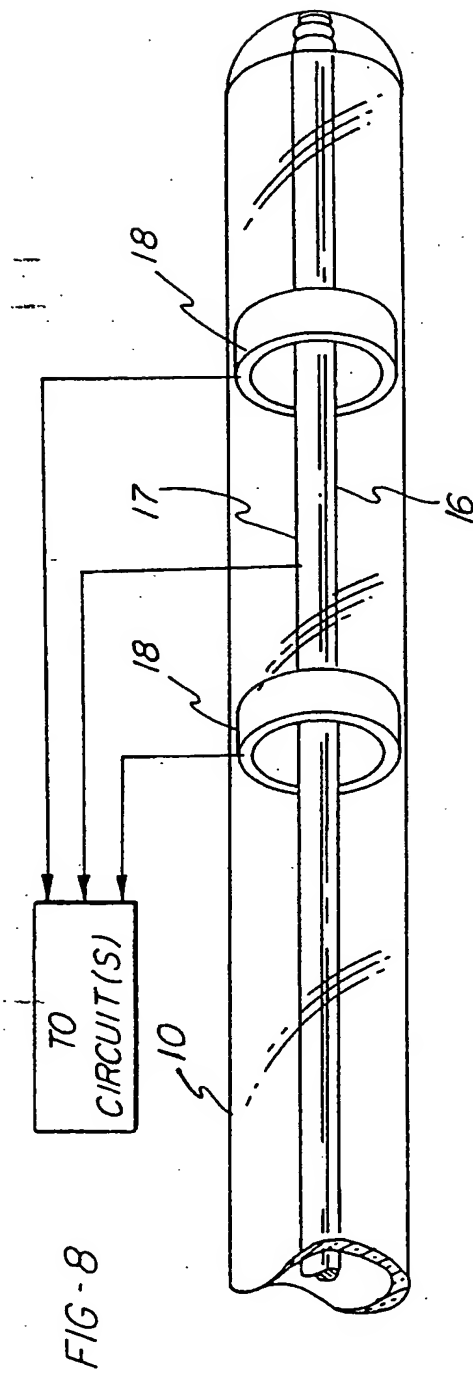


FIG. 6

FIG. 7

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US94/13243

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :A61B 5/026

US CL :128/692

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 128/668, 691, 692, 693, 694, 713

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|-----------|--|-----------------------|
| X | US, A, 3,242,729 (Keller) 29 March 1966, col. 2, line 13 - col. 5, line 6. | 1-13 and 24-45 |
| Y | US, A, 5,031,632 (Watanabe) 16 July 1991, col. 2, lines 28-46. | 14, 21 and 46 |
| Y | US, A, 4,166,455 (Findl et al.) 04 September 1979, col. 5, lines 21-38. | 15-23 |



Further documents are listed in the continuation of Box C.



See patent family annex.

| | | |
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09 JANUARY 1995

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